Estimation of Aerodynamic Derivatives Using Dynamic Wind Tunnel Simulation Technique

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Abstract

This paper presents the results of estimation of the longitudinal and lateral aerodynamic derivatives of a delta winged aircraft model using Dynamic Wind tunnel Simulation Technique. Experiments are conducted using single rotary degree freedom in pitch, roll and yaw axes. Test inputs are applied to the appropriate servo controlled control surfaces namely symmetric elevon, differential elevon and rudder to excite the model in pitch, roll and yaw respectively. The characteristic motion response of the model to the applied test inputs is analysed using parameter estimation techniques to extract the aerodynamic derivative data. The results are compared with derivatives obtained from conventional testing methods namely static wind tunnel test, free oscillation rig and forced oscillation rig which use force/moment data obtained from the model strain gauge balance. A recently developed method of computing neutral point using parameter estimation technique is used to determine the same for this model.

Symbols

b	Wing span,	m
S	Wing area,	sq.m
$\bar{c}$	mean aerodynamic chord,	m
V	free stream velocity,	m/s
$\bar{q}$	dynamic pressure,	N/m^2
α	angle of attack,	radians
β	angle of side slip,	radians
ψ	angle of yaw,	radians
ϕ	angle of roll,	radians
p, q, r	body axis angular rates,	rad/s
Ix, Iy, Iz	moment of inertia about x, y, & z axis respectively	$Kg.m^2$
δ	control surface deflection,	radians
L, M and N	Rolling, Pitching and Yawing moment respectively	
C_{m_α}	Static stability derivative in pitch,	per rad.

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$(C_{m_q} + C_{m_{\dot\alpha}})$	Damping derivative in pitch,	per rad.
$C_{m_{\delta e}}$	Control derivative in pitch,	per rad.
C_{l_β}	Dihedral effect derivative,	per rad.
C_{l_p}	Roll damping derivative,	per rad.
$C_{l_{\delta a}}$	Aileron effectiveness derivative,	per rad.
C_{n_β}	Directional stability derivative,	per rad.
C_{n_r}	Damping derivative in yaw,	per rad.
$C_{n_{\delta r}}$	Rudder effectiveness derivative,	per rad.

Introduction

Recent experience in the design of high performance combat aircraft indicates that the vehicle spends substantial portion of its mission time in the high angle of attack (AoA), high rotational rate maneuvering tasks. Thus it is becoming essential to ascertain, with reasonable certainty, whether the configuration is susceptible to departure leading to spin at these elevated AoA conditions. Hence cost effective prediction of dynamic derivatives using wind tunnel test techniques in the early stages of the aircraft planform optimisation becomes highly desirable. Well established wind tunnel test techniques [1,2,3] such as free and forced oscillation rigs are usually used to compute dynamic derivatives to facilitate prediction of high AoA departures such as wing rock, nose slice and directional divergence. All these techniques use 6 component force and moment data originating from the model mounted strain gauge balances to extract the aerodynamic derivatives. An alternate, not very extensively explored, technique of estimating the derivatives is the use of Dynamic simulation concept [4-9]. This method relies on conducting flight test like experiments in a wind tunnel to estimate the derivatives from motion response of the model to specified test inputs using parameter estimation techniques. This test technique holds promise as a cost effective method for estimating damping derivatives in the preliminary design optimisation of aircraft configuration.

This paper presents the results of such a Dynamic simulation experiment conducted on a delta winged aircraft model. The estimated derivatives are compared with results obtained from conventional wind tunnel test techniques.

Dynamic Wind tunnel Simulation

In a dynamic simulation experiment the model is free to move about a gimbal having rotary and translatory degree of freedom. The model is equipped with servo control surfaces which can be used to excite the model just as in real flight. Miniature incidence, rate and acceleration sensors pick up the dynamic motion of the model. Conventional aircraft parameter estimation analysis techniques [10] are used to extract the aerodynamic derivatives. It can be shown that the key static and damping derivatives of the configuration can be estimated using only rotary degree freedom model suspension. This results in a much simpler experimental set up without loss in the accuracy of estimation. In the present study only rotary degree of freedom experiments have been conducted.

Dynamic Wind Tunnel Facility at NAL

The facility is a 1.2m X 1.2m low speed tunnel of open jet induced draft type, with a variable speed range of 20-60 m/sec. A 170 kW DC motor with variable speed capability drives a 8 blade fan through a 3:1 V-belt drive. In addition, an eleven blade inlet guide-vane driven by electrical actuators provides the facility to rapidly vary the tunnel speed over the base speed set by the motor drive unit. [11,12].

Wind Tunnel Model & Instrumentation

The model chosen for the experiment is a delta winged aircraft configuration for which earlier experimental data is available. The model is fabricated using glass fibre reinforced plastic resulting in light weight. The model gimbal suspension is located at the center of gravity of the model for the pitch and yaw experiment. The model is supported at the back on a low friction bearing assembly for the roll experiments. DC servo motors are used to drive the elevons - symmetric for the pitch experiment and differential for roll experiment. The rudder is driven by a high torque miniature radio controlled servo drive. The control surface positions are measured using miniature precision potentiometers. The model is fitted with a set of strain gauge type accelerometers to sense angular acceleration and also angular attitude with appropriate corrections. Rate gyros are used to sense angular rates. All sensor outputs after suitable signal conditioning are acquired on a Personal Computer(PC) using A/D converters. The control surface command signals are also generated from the PC. Typical signal used for excitation is a doublet.

Dynamic Simulation Experiments

As indicated earlier, three separate single degree of freedom(rotary) experiments are conducted in the pitch, roll and yaw axis. Figure 1 shows a schematic of the test set up. In the pitch experiment the model is trimmed over a range of angle of attack (-5 to 25 deg) using the symmetric elevon servo. At each trim AoA the model response (pitch attitude, rate and acceleration) to a low amplitude elevon doublet input is recorded using the PC based data acquisition system. For the roll and yaw experiments the AoA is fixed by fixing the model pitch attitude mechanically in the range -5 to 25 deg and -5 to 15 deg respectively. For the roll experiments the differential elevon is used to generate the roll response. For the yaw experiments, doublet pulses to the rudder are given and the model yaw angle, rate and acceleration are recorded. In the case of yaw tests additional experiments are conducted by trimming the model at different sideslip angles in the range -10 to 10 deg using rudder.

Analysis of Wind tunnel Data

The wind tunnel model in each degree of freedom tested, behaves as a second order dynamic system and is modelled as a linear time invariant system. The state space formulation for each case is as follows.

Pitch DOF

$$\begin{bmatrix}\dot{\alpha}\\ \dot{q}\end{bmatrix}=\begin{bmatrix}0 & 1\\ M_\alpha & M_q+M_{\dot{\alpha}}\end{bmatrix}\begin{bmatrix}\alpha\\ q\end{bmatrix}+\begin{bmatrix}0\\ M_{\delta e}\end{bmatrix}.\delta e$$

Roll DOF

$$\begin{bmatrix}\dot{\phi}\\ \dot{p}\end{bmatrix}=\begin{bmatrix}0 & 1\\ L_\phi & L_p\end{bmatrix}\begin{bmatrix}\phi\\ p\end{bmatrix}+\begin{bmatrix}0\\ L_{\delta a}\end{bmatrix}.\delta a$$

where $L_\phi = L_\beta / \sin\alpha_0$, α_0 is AoA at which the model is fixed

Yaw DOF

$$\begin{bmatrix}\dot{\psi}\\ \dot{r}\end{bmatrix}=\begin{bmatrix}0 & 1\\ -N_\beta & N_r\end{bmatrix}\begin{bmatrix}\psi\\ r\end{bmatrix}+\begin{bmatrix}0\\ N_{\delta r}\end{bmatrix}.\delta r \qquad \text{where } \psi = -\beta \text{ in our case.}$$

In each case, the measurements are angular attitude, rate and acceleration and a control input. The parameters of the state variable model postulated above are estimated using Maximum Likelihood Estimation (MLE) procedure [13]. Using reference dimensions and test dynamic pressure, non-dimensional derivatives are derived from the dimensional derivatives estimated using MLE. The results are compared with estimates obtained using DATCOM, static wind tunnel tests and free & forced oscillation tests. Figure 2. shows the comparison of the static stability and control derivatives with that deduced from the wind tunnel force/moment test data. The comparisons are very good. Figure 3. shows the comparison of damping derivatives with analytical estimates, free oscillation rig data and forced oscillation rig data. The results obtained from the dynamic simulation results are quite reasonable.

Estimation of Neutral Point of the Model Configuration

The neutral point N_0 is an important longitudinal stability parameter which critically determines the aft CG limit of an aircraft. Since N_0 is a function of aircraft speed, AoA, external store configuration, secondary control surface deployment(slats) etc., conventional flight testing based on steady state trim flight turns out to be time consuming and are error prone due to the results being dependent on airdata and weight data. Recently an alternative flight test method [14] using dynamic maneuvers followed by parameter estimation analysis has been shown to be an accurate and cost effective method of deriving N_0. The new procedure is derived by relating the neutral and maneuver point of an aircraft to key short period parameters M_α and short period natural frequency parameter ω_n^2. The Experiment consists of identifying the short period dynamics of the aircraft at the reference condition at three stable CG conditions. Using graphical procedures, the neutral point is located as the CG position where M_α is zero. and the maneuver point is located at the CG position where ω_n^2 is identically zero. The estimation of the stability parameters using this method are independent of mass, inertia or airdata and depend only on the accuracy of the inertial sensors (rate and acceleration).

Experiments are conducted in the wind tunnel to determine the neutral point using the above method. The pitch degree freedom set up is used. In this experiment since there is no translation degree of freedom (no heave motion) the neutral point is given by the CG position where ω_n^2 is identically zero. Figure 4 shows the neutral point for the model configuration. The neutral point computed is in close agreement with that deduced from static wind tunnel data.

Conclusions

In this paper the estimation of aerodynamic derivatives using Dynamic wind tunnel simulation concept has been presented. Comparison with the conventional force/ moment measurement based wind tunnel test techniques reveals that this method yields comparable results. Thus if the derivative estimation problem is postulated as identifying the parameters of a dynamical system, the powerful system identification tools can be used to accurately determine the derivatives. Use of system identification concepts also change, in a fundamental way, the methodology of conducting both wind tunnel and flight test. The wind tunnel test set up for these dynamic simulation experiments are relatively simple compared to the force/ moment based conventional rigs and have a potential for use in preliminary configuration studies. The specific advantages of the technique over conventional techniques are: i) both static and dynamic derivatives are estimated using a single dynamic maneuver, ii) as the model is trimmed at the reference AoA the results are very close to actual flight test situation, iii) the method provides a direct estimation of the effectiveness of control surfaces and iv) the neutral point of the model can be accurately determined.

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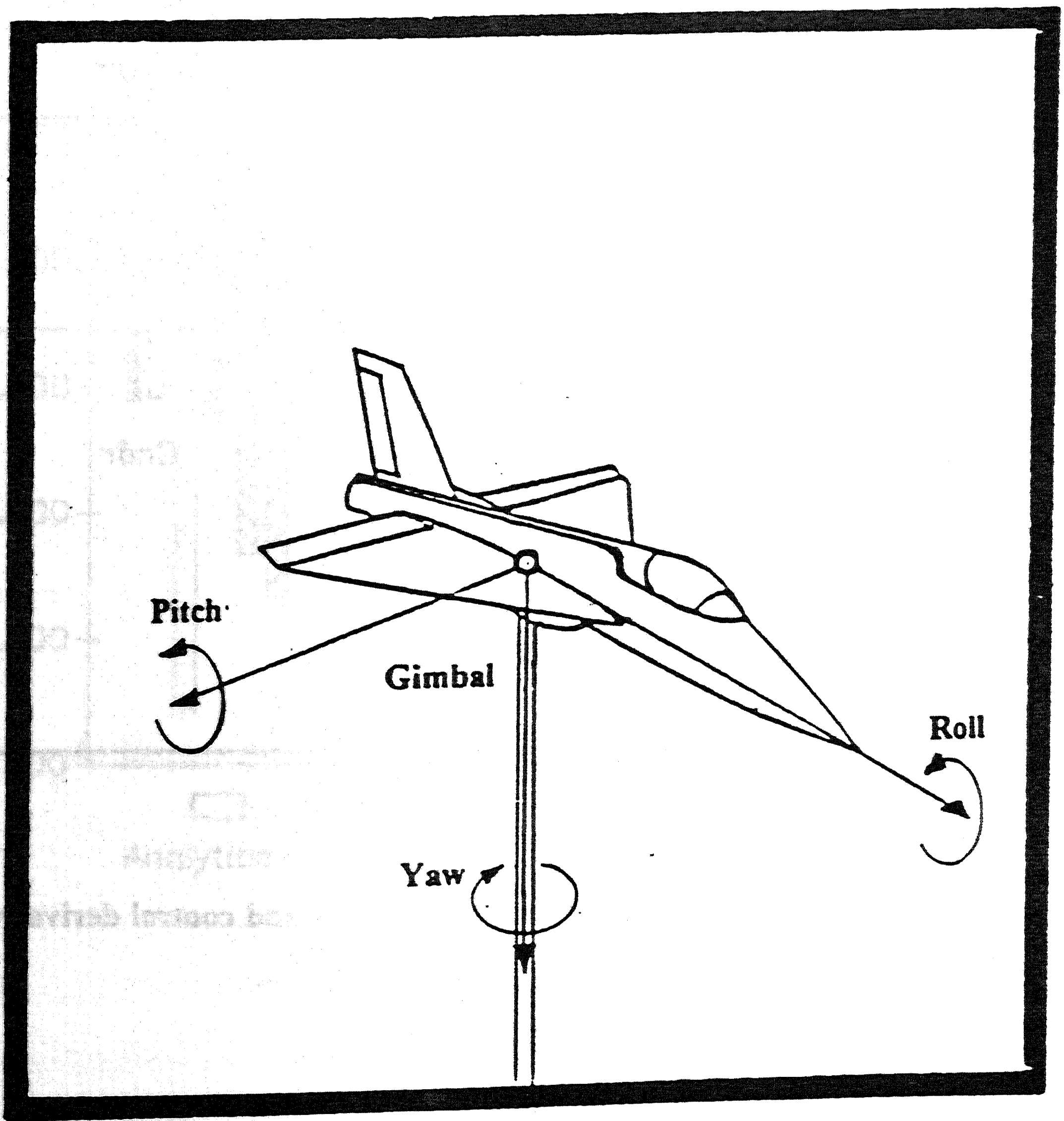

Fig. 1. Schematic of the test set up.

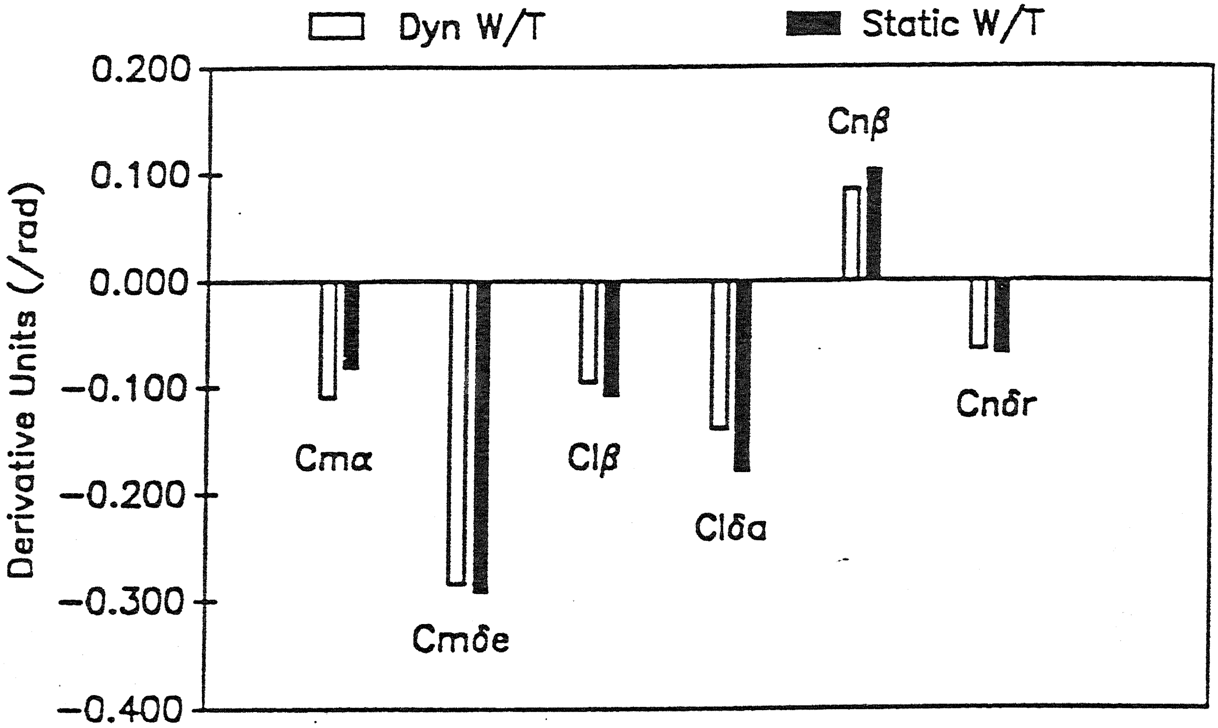

Fig. 2. Comparison of the static stability and control derivatives.

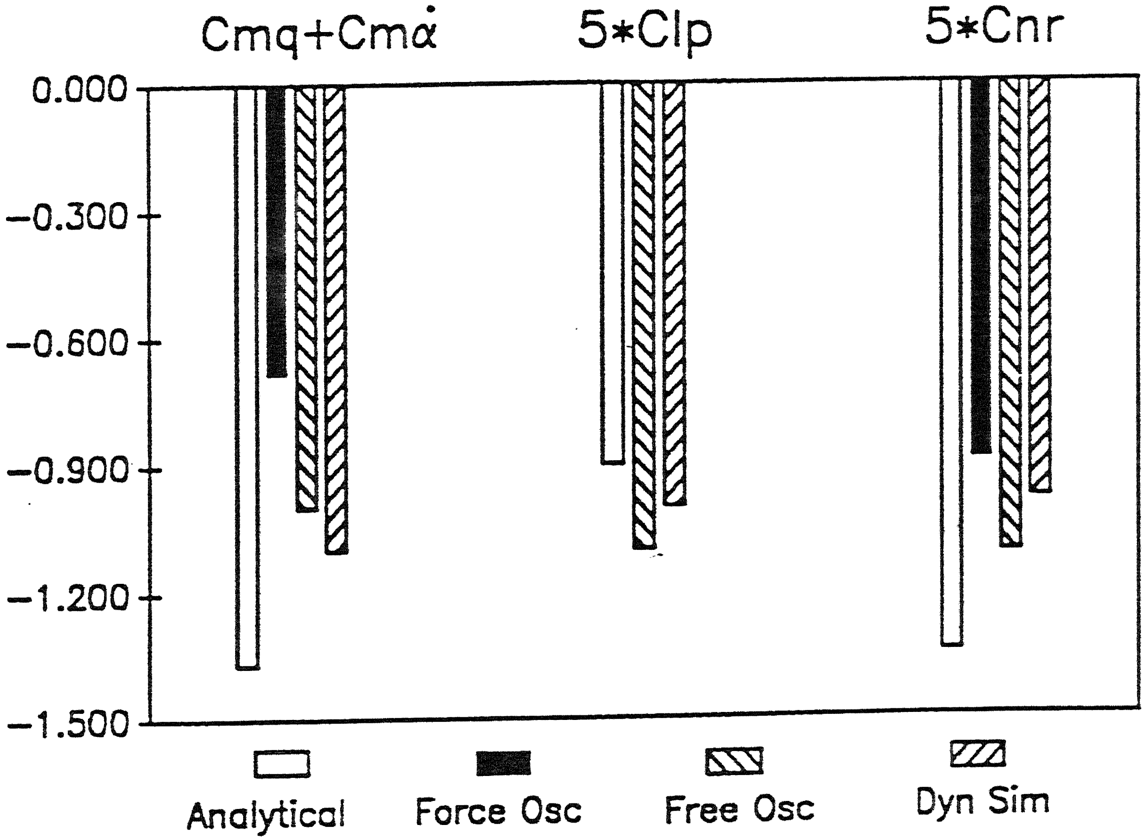

Fig. 3. Comparison of the damping derivatives.

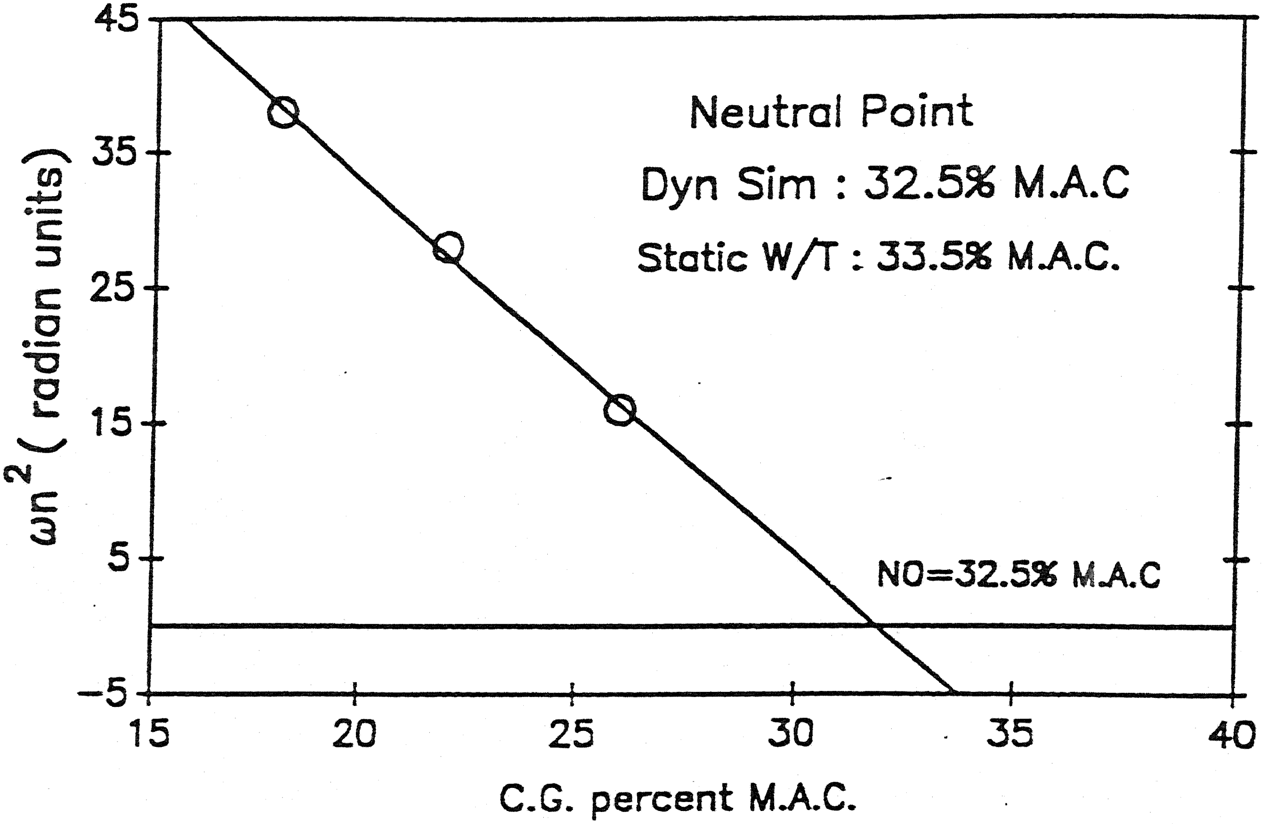

Fig. 4. Determination of Neutral point for the model configuration.